SOLUTION TO ECONOMIC LOAD DISPATCH USING PSO

A thesis submitted in partial fulfillment of the requirements for the degree of

Bachelor of Technology

in

Electrical Engineering

By

MAHESH PRASAD MISHRA,108ee007

Department of Electrical Engineering
National Institute of Technology, Rourkela
May 2012

SOLUTION TO ECONOMIC LOAD DISPATCH USING PSO

A thesis submitted in partial fulfillment of the requirements for the degree of

Bachelor of Technology

in

Electrical Engineering

By

MAHESH PRASAD MISHRA,108ee007

Under supervision of
Prof. Prafulla Chandra Panda

Department of Electrical Engineering
National Institute of Technology, Rourkela
May 2012

NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA

CERTIFICATE

This is to certify that the project report entitled "SOLUTION TO ECONOMIC LOAD DISPATCH USING PSO" submitted by MAHESH PRASAD MISHRA B.Tech Electrical Engineering during session 2011-2012 at National Institute of Technology, Rourkela (Deemed University) is an authentic work by him under my supervision and guidance.

Signature of student
Date:
Rourkela:

Signature of the supervisor
Date:
Rourkela:

ACKNOWLEDGEMENT

I express my gratitude and sincere thanks to my supervisor Prof P.C Panda, Professor Department of Electrical Engineering for his constant motivation and support during the course of my thesis. I truly appreciate and value his esteemed guidance and encouragement from the beginning to the end of this thesis. I am indebted to him for having helped me shape the problem and providing insights towards the solution**.**

I am thankful to my friends, Anurag Mohapatra and Siddhahast Mohapatra, who have done most of the literature review and background study alongside me in their similar project work.

I extend my gratitude to the researchers and scholars whose hours of toil have produced the papers and theses that I have utilized in my project.

Mahesh Prasad Mishra

ABSTRACT

The modern power system around the world has grown in complexity of interconnection and power demand. The focus has shifted towards enhanced performance, increased customer focus, low cost, reliable and clean power. In this changed perspective, scarcity of energy resources, increasing power generation cost, environmental concern necessitates optimal economic dispatch. In reality power stations neither are at equal distances from load nor have similar fuel cost functions. Hence for providing cheaper power, load has to be distributed among various power stations in a way which results in lowest cost for generation. Practical economic dispatch (ED) problems have highly non-linear objective function with rigid equality and inequality constraints. Particle swarm optimization (PSO) is applied to allot the active power among the generating stations satisfying the system constraints and minimizing the cost of power generated. The viability of the method is analyzed for its accuracy and rate of convergence. The economic load dispatch problem is solved for three and six unit system using PSO and conventional method for both cases of neglecting and including transmission losses. The results of PSO method were compared with conventional method and were found to be superior. The conventional optimization methods are unable to solve such problems due to local optimum solution convergence. Particle Swarm Optimization (PSO) since its initiation in the last 15 years has been a potential solution to the practical constrained economic load dispatch (ELD) problem. The optimization technique is constantly evolving to provide better and faster results.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1:

INTRODUCTION

With large interconnection of the electric networks, the energy crisis in the world and continuous rise in prices, it is very essential to reduce the running costs of electric energy. A saving in the operation of the power system brings about a significant reduction in the operating cost as well as in the quantity of fuel consumed. The main aim of modern electric power utilities is to provide high-quality reliable power supply to the consumers at the lowest possible cost while operating to meet the limits and constraints imposed on the generating units and environmental considerations. These constraints formulates the economic load dispatch **(ELD)** problem for finding the optimal combination of the output power of all the online generating units that minimizes the total fuel cost, while satisfying an equality constraint and a set of inequality constraints. Traditional algorithms like lambda iteration, base point participation factor, gradient method, and Newton method can solve this ELD problems effectively if and only if the fuel-cost curves of the generating units are piece-wise linear and monotonically increasing . Practically the input to output characteristics of the generating units are highly non-linear, non-smooth and discrete in nature owing to prohibited operating zones, ramp rate limits and multifuel effects. Thus the resultant ELD becomes a challenging non-convex optimization problem, which is difficult to solve using the traditional methods.Methods like dynamic programming, genetic algorithm, evolutionary programming, artificial intelligence, and particle swarm optimization solve non-convex optimization problems efficiently and often achieve a fast and near global optimal solution. Among them PSO was developed through simulation of a simplified social system, and has been found to be robust in solving continuous non-linear optimization problems. The PSO technique can generate high-quality solutions within shorter calculation time and stable convergence characteristics.

CHAPTER 2:

BACKGROUND & LITERATURE REVIEW

2.1 THERMAL POWER PLANT

A thermal power plant is a power plant in which its prime-mover is driven by steam. Water is the working fluid. It is heated at the boiler and circulated with energy to be expanded at the steam turbine to give work to the rotor shaft of the generator. After it passes through the turbine, it is condensed in a condenser and then pumped to feed the boiler where it is heated up.

For simplification, thermal power plants can be modelled as a transfer function of energy conversion from fossil fuel to electricity as described in Fig

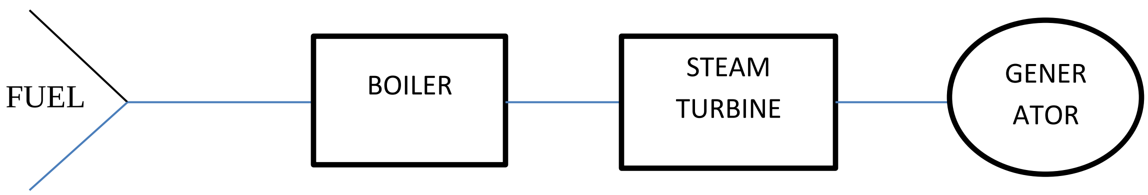


Fig.1 Energy conversion diagram of a thermal power plant.

The thermal unit system generally consists of the boiler, the steam turbine, and the generator. The input of the boiler is fuel, and the output is the volume of steam. The relationship of the input and output can be expressed as a convex curve .The input of the turbine-generator unit is the volume of steam and the output is electrical power, the overall input-output characteristic of the whole generation unit can be obtained by combining directly the input-output characteristic of the boiler and the input-output characteristic of the turbine-generator unit. It is a convex curve.

2.2 OPERATING COST OF A THERMAL POWER PLANT:

The factors influencing power generation are operating efficiencies of generators, fuel cost and transmission losses. The total cost of generation is a function of the individual generation of the sources which can take values within certain constraints. The problem is to determine the generation of different plants such that total operating cost is minimum. The input to the thermal plant is generally measured in Btu/hr and the output power is the active power in MW. A simplified input-output curve of a thermal unit known as heat-rate curve

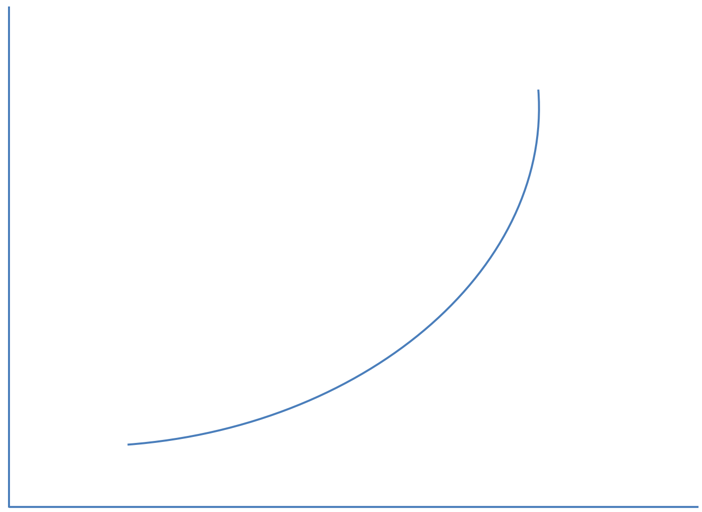


Fig 2. Input Output characteristics of generator unit

In all practical cases, the fuel cost of any generator unit 'i' can be represented as a quadratic function of the real power generation.

$C_i = A_i {*} P_i^2 + B_i {*} P_i + C_i$

The incremental fuel-cost curve is a measure of how costly it will be to produce the next increment of power.

$dC_i/dP_i = 2A_i {*} P_i + B_i$

2.3 CALCULATION OF INPUT-OUTPUT CHARACTERISTIC PARAMETERS:

The parameters of the input-output characteristic of any generating unit can be determined by the following approaches

1. Based on the experiments of the generating unit efficiency.

2. Based on the historic records of the generating unit operation.

3. Based on the design data of the generating unit provided by manufacturer.

In the Practical power systems, we can easily obtain the fuel statistic data and power output statistics data. Through analyzing and computing data set (Fk, Pk), we can determine the shape of the input-output characteristic and the corresponding parameters.

2.4 SYSTEM CONSTRAINTS:

Generally there are two types of constraints [3]

i) Equality constraints

ii) Inequality constraints

2.4.1 EQUALITY CONSTRAINTS

The equality constraints are the basic load flow equations of active and reactive power[3].

$$\sum_{i=1}^{N} P_i - P_D - P_L = 0$$

2.4.2 INEQUALITY CONSTRAINTS:

i) Generator Constraints:

The KVA loading of a generator can be represented as $\sqrt{P^2 + Q^2}$. The KVA loading should not exceed a pre-specified value to limit the temperature rise. The maximum active power generated 'P' from a source is also limited by thermal consideration to keep the temperature rise within limits. The minimum power generated is limited by the flame instability of the boiler. If the power generated out of a generator falls below a pre-specified value Pmin, the unit is not put on the bus bar.

$$P_{min} \leq P \leq P_{max}$$

• The maximum reactive power is limited by overheating of rotor and minimum reactive power is limited by the stability limit of machine. Hence the generator reactive powers Q should not be outside the range stated by inequality for its stable operation.

$$Q_{min} \leq Q \leq Q_{max}$$

ii) Voltage Constraints:

The voltage magnitudes and phase angles at various nodes should vary within certain limits. The normal operating angle of transmission shoul lie between 30 to 45 degrees for transient stability reasons. A higher operating angle reduces the stability during faults and lower limit of delta assures proper utilization of the available transmission capacity.

iii) Running Spare Capacity Constraints:

These constraints are required to meet

a) The forced outages of one or more alternators on the system &

b) The unexpected load on the system.

The total generation should be such that in addition to meeting load demand and various losses a minimum spare capacity should be available i.e.

$$G \geq P_p + P_{so}$$

Where G is the total generation and P_{so} is some pre-specified power. A well planned system has minimum P_{so}. [3]

iv) Transmission Line Constraints:

The flow of active and reactive power through the transmission line circuit is limited by the thermal capability of the circuit and is expressed as.

$C_p \leq C_{pmax}$; Where C_{pmax} is the maximum loading capacity of the P^{th} line. [3]

v) Transformer tap settings:

If an auto-transformer is used, the minimum tap setting could be zero and maximum one, i.e. $0 \leq t \leq 1.0$

Similarly for a two winding transformer if tapping are provided on the secondary side,

$0 \leq t \leq n$ where n is the ratio of transformation. [3]

vi) Network security constraints:

If initially a system is operating satisfactorily and there is an outage, may be scheduled or forced one, it is natural that some of the constraints of the system will be violated. The complexity of these constraints (in terms of number of constraints) is enhanced when a large system is being analyzed. In this a study is to be made with outage of one branch at a time and then more than one branch at a time. The natures of the constraints are same as voltage and transmission line constraints. [3]

2.5 OPTIMUM LOAD DISPATCH:

The optimum load dispatch problem involves the solution of two different problems. The first of these is the unit commitment or pre dispatch problem wherein it is required to select optimally out of the available generating sources to meet the expected load and provide a specified margin of operating reserve over a specified period time .The second aspect of economic dispatch is the on-line economic dispatch wherein it is required to distribute the load among the generating units paralleled with the system in such manner so as to minimize the total cost of operation.

2.6 COST FUNCTION

Let C_i represent the cost, expressed in Rs per hour, of producing energy in the i^{th} generator. $C = \sum_{i=1}^{N} C_i$ Rs/hrs. The generated real power P_{Gi} has a major influence on the cost function. The individual real power generation can be raised by increasing the prime mover torque which requires an increased expenditure of fuel. The reactive generations Q_{Gi} do not have any significant influence on Ci because they are controlled by controlling the field excitation. The individual production cost Ci of generator units is therefore for all practical purposes considered a function only of P_{Gi} , and for the overall production cost C, we thus have

$$C = \sum_{i=1}^{N} C_i(P_{Gi})$$

2.7 PARTICLE SWARM OPTIMIZATION:

Most of the conventional computing algorithms are not effective in solving real-world problems because of having an inflexible structure mainly due to incomplete or noisy data and some multi-dimensional problems. Natural computing methods are best suited for solving such problems. In general Natural computing methods can be divided into three categories:

1) Epigenesis

2) Phylogeny

3) Ontogeny.

PSO belongs to the Ontogeny category in which the adaptation of a special organism to its environment is considered.

2.8 DESCRIPTION OF PSO:

Particle Swarm Optimization (PSO) is a biologically inspired computational search and optimization method developed by Eberhart and Kennedy in 1995 based on the social behaviours of birds flocking and fish schooling.

Particle (X): It is a candidate solution represented by an m-dimensional vector, where m is the number of optimized parameters. At time t, the i^{th} particle $X_i(t)$ can be described as $X_i(t)=[X_{i1}(t), X_{i2}(t),.., X_{in}(t)]$, where X_s are the optimized parameters and $X_{ik}(t)$ is the position of the i^{th} particle with respect to the k^{th} dimension; i.e. the value of the k^{th} optimized parameter in the i^{th} candidate solution.

Population, Pop (t): It is a set of n particle at time t, i.e. Pop (t) $=[X_1(t), X_2(t),.., X_n(t)]$.

Swarm: It is an apparently disorganized population of moving particles that tend to cluster together towards a common optimum while each particle seems to be moving in a random direction.

Personal best (Pbest): The personal best position associated with i^{th} particle is the best position that the particle has visited yielding the highest fitness value for that particle.

Global best (Gbest): The best position associated with i^{th} particle that any particle in the swarm has visited yielding the highest fitness value for that particle. This represents the best fitness of all the particles of a swarm at any point of time.

The optimization process uses a number of particles constituting a swarm that moves around a pre-defined search space looking for the best solution. Each particle is treated as a point in the D-dimensional space in which the particle adjusts its “flying” according to its own flying experience as well as the flying experience of other neighbouring particles of the swarm. Each particle keeps track of its coordinates in the pre-defined space which are associated with the best solution (fitness) that it has achieved so far. This value is called pbest. Another best value that is tracked by the PSO is the best value obtained so far by any particle in the whole swarm. This value is called gbest. The concept consists of changing the velocity of each particle toward its pbest and the gbest position at the end of every iteration. Each particle tries to modify its current position and velocity according to the distance between its current position and pbest, and the distance between its current position and gbest.[6]

CHAPTER 3:

METHODOLOGY

PROBLEM FORMULATION

ECONOMIC LOAD DISPATCH NEGLECTING LOSSES

ELD WITH LOSS

FORMULATION OF PSO

APPLICATION OF PSO METHOD TO ECONOMIC LOAD DISPATCH

3.1 PROBLEM FORMULATION:

The objective of the economic load dispatch problem is to minimize the total fuel cost.

$$\text{Min } F_T = \sum_{n=1}^{N} Fn$$

$$\text{Subject to } P_D + P_L = \sum_{n=1}^{N} Pn$$

3.2 ECONOMIC LOAD DISPATCH NEGLECTING LOSSES[3]

LAGRANGIAN MULTIPLIER (LAMBDA-ITERATION) METHOD:

$$F = F_T + \lambda(P_D - \sum_{n=1}^{N} Pn)$$

Where λ is the Lagrangian Multiplier.

Differentiating F with respect to the generation P_n and equating to zero gives the condition for optimal operation of the system.

$$\partial F / \partial P_n = \partial F_T / \partial P_n + \lambda(0-1) = 0$$

$$= \partial F_T / \partial P_n - \lambda = 0$$

Since $F_T = F_1 + F_2 \ldots\ldots\ldots\ldots + F_N$

$$\partial F_T / \partial P_n = dF_n / dP_n = \lambda$$

Therefore the condition for optimum operation is

$dF_1/dP_1 = dF_2/dP_2 = \ldots\ldots\ldots\ldots = dF_n/dP_n$

The incremental production cost of a given plant over a limited range is represented by

$dF_n/dP_n = F_{nn}P_n + f_n$

F_{nn}= slope of incremental production cost curve

f_n= intercept of incremental production cost curve

The active power generation constraints are taken into account while solving the equations which are derived above. If these constraints are violated for any generator it is limited to the corresponding limit and the rest of the load is distributed among the remaining generator units according to the equal incremental cost of production.

3.3 ELD WITH LOSS:[3]

The optimal load dispatch problem including transmission losses is defined as

$$\text{Min } F_T = \sum_{n=1}^{N} Fn$$

$$\text{Subject to } P_D + P_L - \sum_{n=1}^{N} Pn$$

Where P_L is the total system loss which is assumed to be a function of generation

Making use of the Lagrangian multiplier λ, the auxiliary function is given by

$$F = F_T + \lambda\, (P_D + P_L - \sum_{n=1}^{N} Pn)$$

The partial differential of this expression when equated to zero gives the condition for optimal

Load dispatch, i.e.

$$\partial F / \partial P_n = \partial F_T + \lambda(\partial P_L / \partial P_n - 1)$$

$dF/dP_n + \lambda * \partial P_L / \partial P_n = \lambda$

Here the term $\partial P_L / \partial P_n$ is known as the incremental transmission loss at plant n and λ is known as the incremental cost of received power in Rs.per MWhr. The above equation is a set of n equations with (n+1) unknowns ie. ‘n’ generations are unknown and λ is unknown. These equations are also known as coordination equations because they coordinate the incremental transmission losses with the incremental cost of production.

To solve these equations the loss formula is expressed in terms of generations as

$P_L = \sum_m \sum_n P_m B_{mn} P_n$

Where P_m and P_n are the source loadings, B_{mn} the transmission loss coefficient.

$$\partial P_L / \partial P_N = 2\sum_m B_{mn} P_m$$

Also $dF_n/dP_n = F_{nn}P_n + f_n$

∴ The coordination equation can be rewritten as

$$F_{mn} P_n + f_n + \lambda \sum 2 B_{mn} P_m = \lambda$$

Solving for P_n we obtain

$P_n = (1 - f_n/\lambda * \sum_{m!=n} 2 B_{mn} P_m) / (F_n/\lambda + 2B_{nn})$

When transmission losses are included and coordinated, the following points must be kept in mind for economic load dispatch solution

1. Whereas incremental transmission cost of production of a plant is always positive, the incremental transmission losses can be both positive and negative.

2. The individual generators will operate at different incremental costs of production.

3. The generation with highest positive incremental transmission loss will operate at the lowest incremental cost of production.

3.4 FORMULATION OF PSO:

PSO is initialized with a group of random particles (solutions) and then searches for optima by updating generations. In every iteration, each particle is updated by following two "best" values. The first one is the best solution (fitness) it has achieved so far. This value is called pbest. Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the population. This best value is a global best and called g-best. After finding the two best values, the particle updates its velocity and positions according to the following equations.[2]

$$V_i^{(u+1)} = w*V_i^{(u)} + C_1*rand(\ )*(pbest_i - P_i^{(u)}) + C_2*rand(\ )*(gbest_i - P_i^{(u)})$$
$$P_i^{(u+1)} = P_i^{(u)} + V_i^{(u+1)}$$

In the above equation,The term rand ( )*($pbest_i$ - $P_i^{(u)}$) is called particle memory influence

The term rand ( )*($gbest_i$ -$P_i^{(u)}$) is called swarm influence.

In the above equation, C1 generally has a range (1.5,2) which is called as the self-confidence range and C2 generally has a range (2, 2.5) which is known as the swarm range. $V_i^{(t)}$ which is the velocity of the ith particle at iteration 'i' should lie in the pre-specified range (Vmin,Vmax). The parameter Vmax determines the resolution with which regions are to be searched between the present position and the target position. If Vmax is too high, particles may fly past good solutions. If Vmax is too small particles may not explore sufficiently beyond local solutions. Vmax is often set at 10-20% of the dynamic range on each dimension.

The constants C1 and C2 pull each particle towards pbest and gbest positions. Low values allow particles to roam far from the target regions before being tugged back. On the other hand, high values result in abrupt movement towards, or past, target regions. Hence the acceleration constants C1 and C2 are often set to be 2.0 according to past experiences.

The inertia constant can be either implemented as a fixed value or can be dynamically changing. This parameter controls the exploration of the search space. Suitable selection of inertia weight 'ω' provides a balance between global and local explorations, thus requiring less iteration on average to find a sufficiently optimal solution. As originally developed, ω often decreases linearly from about 0.9 to 0.4 during a run. In general, the inertia weight *w* is set according to the following equation,

$$W = W_{\max} - \left[\frac{W_{\max} - W_{\min}}{ITER_{\max}} \right] * ITER$$

Where W -is the inertia weighting factor

W_{max} - maximum value of weighting factor

W_{min} - minimum value of weighting factor

ITER – Current iteration number

$ITER_{max}$-Maximum iteration number.

3.5 APPLICATION OF PSO METHOD TO ECONOMIC LOAD DISPATCH

STEPS OF IMPLEMENTATION:

1. Initialize the Fitness Function ie. Total cost function from the individual cost function of the various generating stations.

2. Initialize the PSO parameters Population size, C1, C2, W_{MAX}, W_{MIN}, error gradient etc.

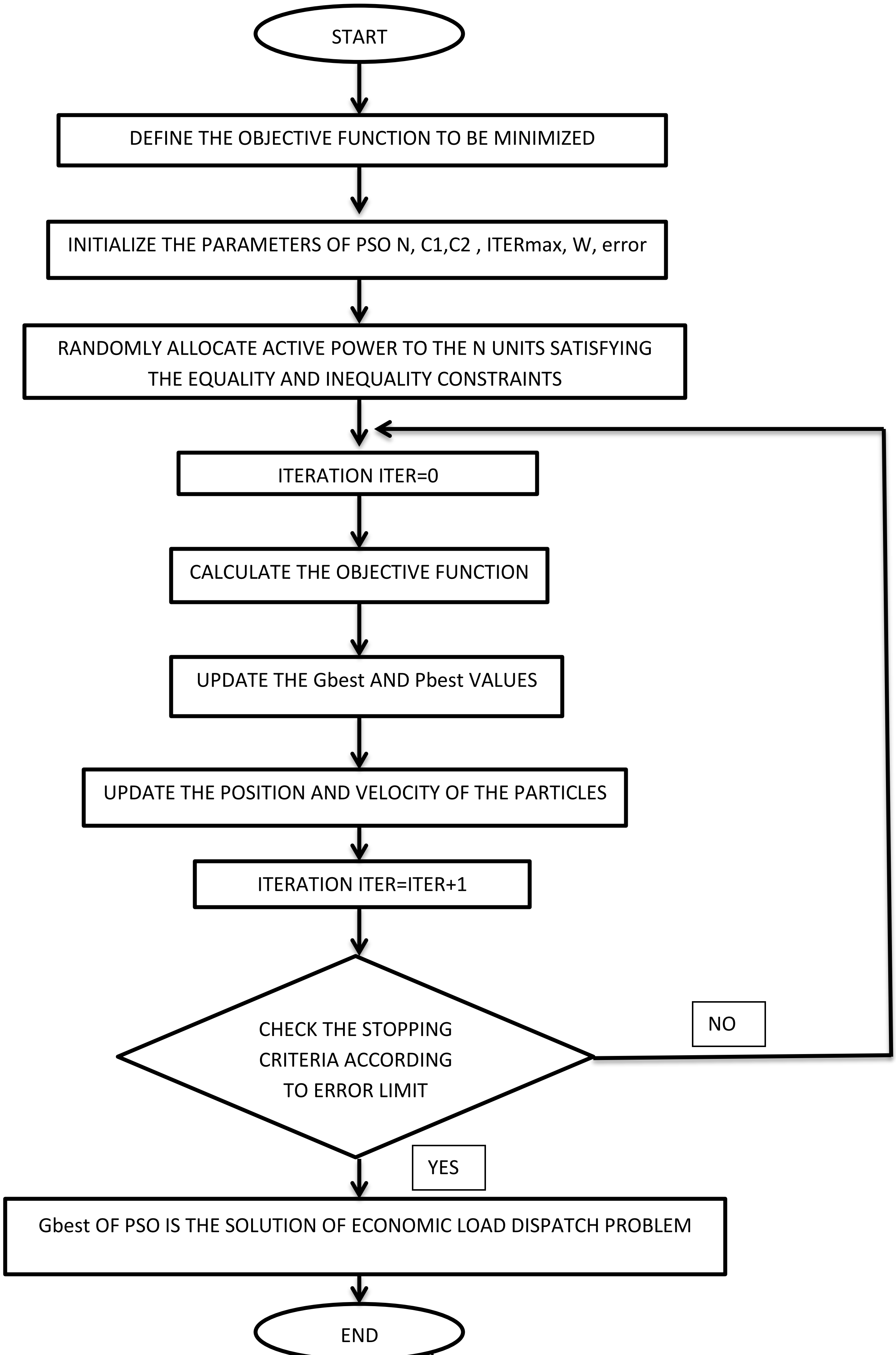
3. Input the Fuel cost Functions, MW limits of the generating stations along with the B-coefficient matrix and the total power demand.

4. At the first step of the execution of the program a large no(equal to the population size) of vectors of active power satisfying the MW limits are randomly allocated.

5. For each vector of active power the value of the fitness function is calculated. All values obtained in an iteration are compared to obtain Pbest. At each iteration all values of the whole population till then are compared to obtain the Gbest. At each step these values are updated.

6. At each step error gradient is checked and the value of Gbest is plotted till it comes within the pre-specified range.

7. This final value of Gbest is the minimum cost and the active power vector represents the economic load dispatch solution.


START
DEFINE THE OBJECTIVE FUNCTION TO BE MINIMIZED
INITIALIZE THE PARAMETERS OF PSO N, C1,C2 , ITERmax, W, error
RANDOMLY ALLOCATE ACTIVE POWER TO THE N UNITS SATISFYING THE EQUALITY AND INEQUALITY CONSTRAINTS
ITERATION ITER=0
CALCULATE THE OBJECTIVE FUNCTION
UPDATE THE Gbest AND Pbest VALUES
UPDATE THE POSITION AND VELOCITY OF THE PARTICLES
ITERATION ITER=ITER+1
CHECK THE STOPPING CRITERIA ACCORDING TO ERROR LIMIT
NO
YES
Gbest OF PSO IS THE SOLUTION OF ECONOMIC LOAD DISPATCH PROBLEM
END

CHAPTER 4

RESULT

THREE UNIT THERMAL SYSTEM

SIX UNIT THERMAL SYSTEM

EFFECT OF WEIGHT FACTOR ON CONVERGENCE

CASE STUDY 1: THREE UNIT THERMAL SYSTEM

CONVENTIONAL (LAGRANGE MULTIPLIER) METHOD[1]**.**

The cost characteristics of the three units are given as[5]:

$F1 = 0.00156P_1^2 + 7.92\ P_1 + 561$ Rs/Hr

$F2 = 0.00194P_2^2 + 7.85\ P_2 + 310$ Rs/Hr

$F3 = 0.00482P_3^2 + 7.97\ P_3 + 78$ Rs/Hr

The unit operating constraints are:

100 MW ≤ P1 ≤ 600 MW

100 MW ≤ P2 ≤ 400 MW

50 MW ≤ P3 ≤ 200 MW

B-Coefficient Matrix:

B=1e-4*[0.75 0.05 0.075
0.05 0.15 0.10
0.075 0.10 0.45];

For the above system considering loads of 585MW, 600MW, 700MW & 800MW conventional lagrange multiplier method is applied to obtain the economic load dispatch. Table 1 shows the economic load dispatch of the above mentioned loads neglecting the transmission line losses.

Table 1: lambda iteration method neglecting losses for Three unit system.

Sl No.	POWER DEMAND(MW)	P1(MW)	P2(MW)	P3 (MW)	LAMBDA	TOTAL FUEL COST(Rs/hr)
1	585	268.8938	234.2651	81.8411	8.758949	5821.44
2	600	275.9434	239.9339	84.1228	8.780943	5952.99
3	700	322.9408	277.7256	99.335	8.927575	6838.41
4	800	369.9383	315.5174	114.5443	9.074207	7738.50

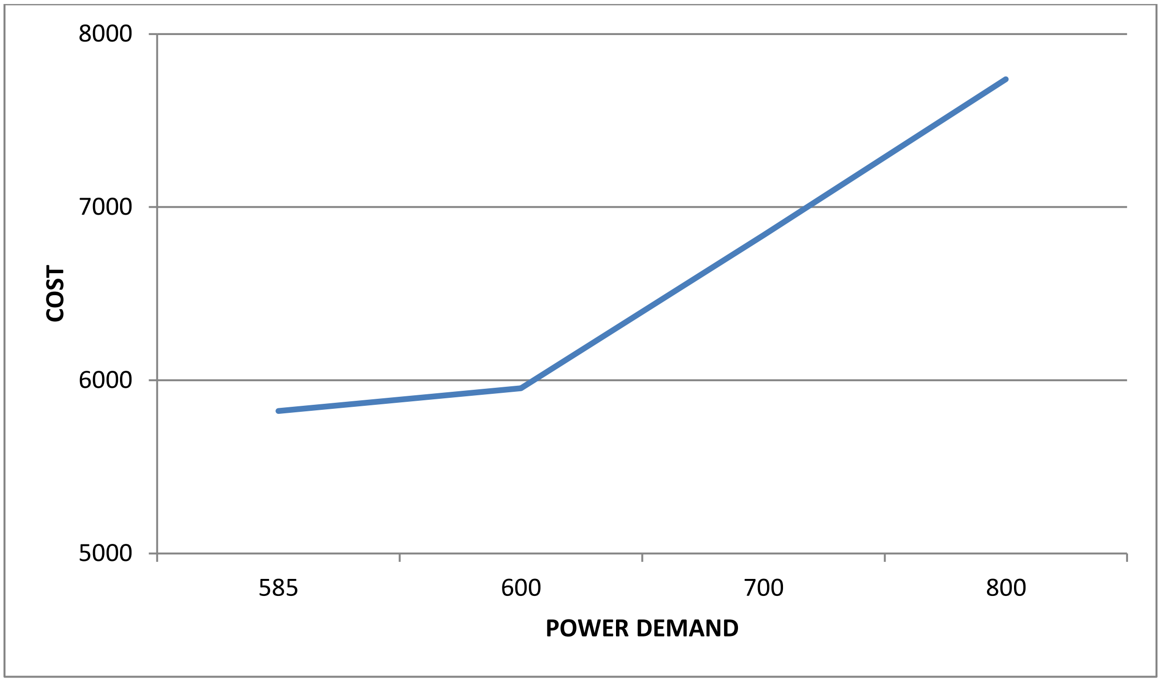


Fig 3: Variation of Cost with Power Demand for Three unit system.

Table 2 shows the economic load dispatch result of the system including the transmission line losses. The transmission line losses are calculated with the help of the B-Coefficient matrix.

Table 2: lambda iteration method including transmission losses for Three unit system.

Sl No.	POWER DEMAND(MW)	P1(MW)	P2(MW)	P3(MW)	PL(MW)	LAMBDA	TOTAL FUEL COST(Rs/hr)
1	585	233.2525	267.8646	90.8404	6.9574	8.998969	5886.94
2	600	239.3315	274.5930	93.4005	7.3250	9.028266	6022.14
3	700	279.8153	319.6721	110.5326	10.02	9.225003	6934.79
4	800	320.2224	365.1414	127.7777	13.1415	9.424247	7867.23

PARTICLE SWARM OPTIMIZATION METHOD:

PSO was applied to the above system for obtaining economic load dispatch of similar load requirements. PSO was implemented according to the flow chart shown. For each sample load, under the same objective function and individual definition, 20 trials were performed to observe the evolutionary process and to compare their solution quality, convergence characteristic and computation efficiency.[7]

PSO METHOD PARAMETERS:

POPULATION SIZE: 100

MAXIMUM NO OF ITERATION: 100000

INERTIA WEIGHT FACTOR (w): W_{max}=0.9 & W_{min}=0.4

ACCELERATION CONSTANT: C1=2 & C2=2

ERROR GRADIENT: 1e-06

Table 3: Optimal Scheduling of Generators of a Three-unit system by PSO Method (Loss neglected case).

Sl No.	POWER DEMAND(MW)	P1(MW)	P2(MW)	P3(MW)	TOTAL FUEL COST(Rs/hr)
1	585	269.197877	234.1305213	81.67160164	5821.439522
2	700	322.9600445	277.7589543	99.28100114	6838.414351
3	800	369.3035563	316.0107041	114.6857396	7738.504671

Table 4: Comparison of results between Conventional method and PSO method for Three-unit system (Loss Neglected Case).

SI.No.	Power Demand (MW)	Conventional Method (Rs/Hr)	PSO Method (Rs/Hr)
1	585	5821.44	5821.439522
2	700	6838.41	6838.414351
3	800	7738.50	7738.504671

Table 5: Optimal Scheduling of Generators of a Three-unit system by PSO Method (Loss included case).

Sl No	Power Demand (MW)	P1 (MW)	P2 (MW)	P3 (MW)	TOTAL FUEL COST(Rs/hr)	Loss, PL (MW)
1	585.33	232.8748377	268.4188941	90.9882212	5889.911604	6.95195306
2	812.57	325.5186488	370.5441529	130.0807258	7985.85097	13.57353

Table 6: Comparison of results between Classical Method and PSO method of a Three-unit system (Loss included Case).

Sl No.	Power Demand (MW)	Conventional Method (Rs/Hr)	PSO Method (Rs/Hr)
1	585.33	5889.91	5889.911604
2	812.57	7985.85	7985.85097

For Power demands of 585 MW, 700 MW, 800 MW neglecting losses the total fuel cost for 20 runs is observed to study the reliability of the solution provided by this method.

Table 7 Reliability Evaluation of PSO method.

Sl No.	Power Demand (MW)	Min(MW)	Mean(MW)	Std Deviation(MW)
1	585	5821.439522	5821.44772	0.009738965
2	700	6838.414351	6838.420074	0.006164467
3	800	7738.504671	7738.51086	0.009240757

For Power demand of 700 MW the total fuel cost obtained for 20 runs is plotted to study the reliability of the method.

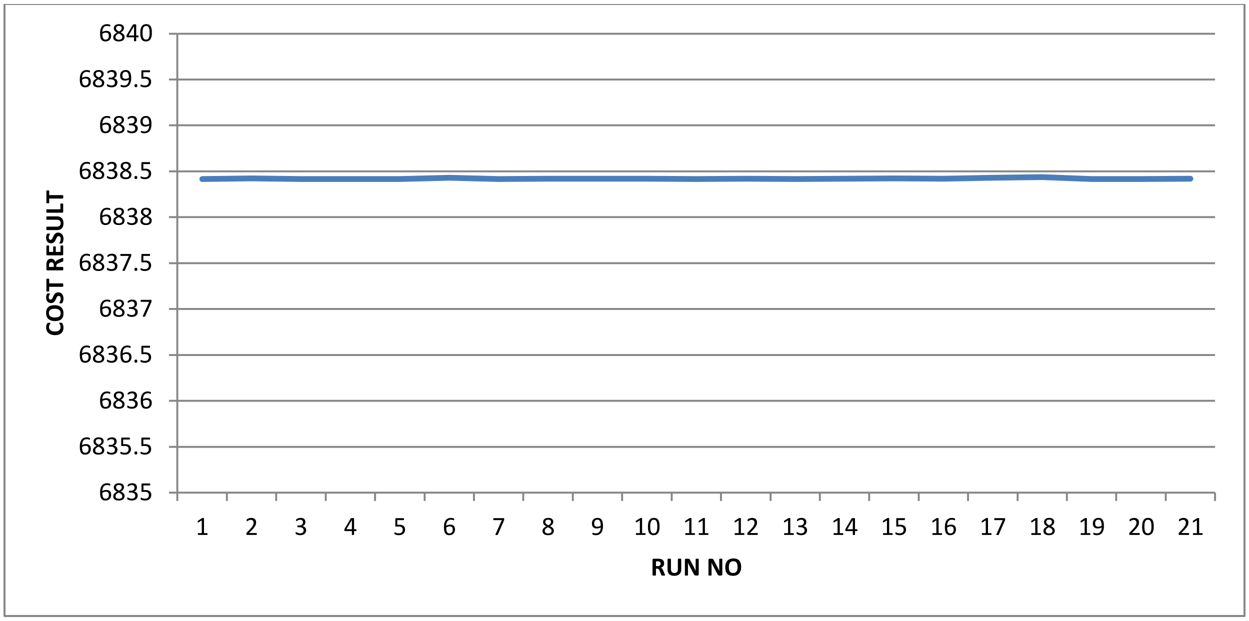


Fig.4 Reliability Evaluation of PSO Method Three unit System.

For a Power Demand of 800 MW loss neglected TOTAL FUEL COST with ITERATION NO was plotted to study the nature of convergence of the method.

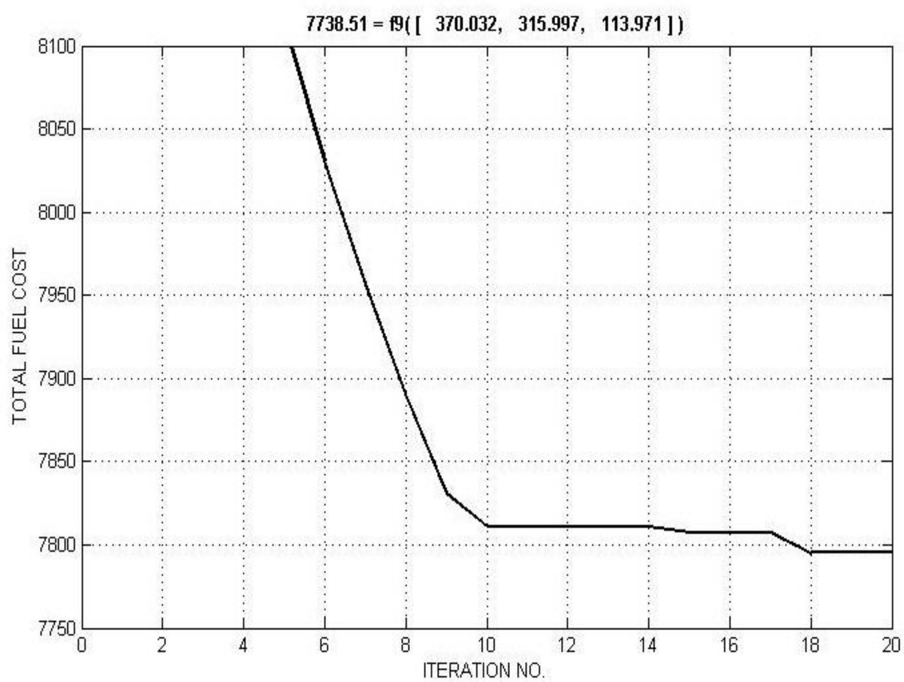


Fig.5 Convergence Characteristics of PSO Method for Three unit System.

CASE STUDY 1: SIX UNIT THERMAL SYSTEM

CONVENTIONAL (LAGRANGE MULTIPLIER) METHOD

The cost characteristics of the three units in Rs/hr are given as:

$F1=0.15240P1^2+38.53973P1+756.79886$

$F2 = 0.10587P2^2+ 46.15916P2 +451.32513$

$F3 = 0.02803P3^2+ 40.39655P3+1049.9977$

$F4 = 0.03546P4^2+ 38.30553P4+1243.5311$

$F5 = 0.02111P5^2+ 36.32782P5+1658.5596$

$F6 = 0.01799P6^2+ 38.27041P6+1356.6592$

The unit operating constraints are:

$10 \text{ MW} \leq P1 \leq 125 \text{ MW}$; $10 \text{ MW} \leq P2 \leq 150 \text{ MW}$;

$35 \text{ MW} \leq P3 \leq 225 \text{ MW}$; $35 \text{ MW} \leq P4 \leq 210 \text{ MW}$;

$130 \text{ MW} \leq P5 \leq 325 \text{ MW}$; $125 \text{ MW} \leq P6 \leq 315 \text{ MW}$

B-Coefficient Matrix:

B=[0.000140 0.000017 0.000015 0.000019 0.000026 0.000022
0.000017 0.000060 0.000013 0.000016 0.000015 0.000020
0.000015 0.000013 0.000065 0.000017 0.000024 0.000019
0.000019 0.000016 0.000017 0.000071 0.000030 0.000025
0.000026 0.000015 0.000024 0.000030 0.000069 0.000032
0.000022 0.000020 0.000019 0.000025 0.000032 0.000085];

Table 8: lambda iteration method neglecting losses for Six unit system.

SL No.	Power demand	P1	P2	P3	P4	P5	P6	Lambda	Total Fuel Cost
1	700	24.9737	10	102.6610	110.6345	232.6837	219.0471	46.151725	36003.12
2	800	28.758	10	123.2359	126.8983	260.0032	251.1047	47.305155	40675.97
3	900	32.5113	10.8153	143.6431	143.0295	287.1	282.9008	48.449182	45464.08
4	1000	36.1001	15.9812	163.1551	158.4531	313.0082	313.3023	49.543026	50363.69
5	1100	43.1896	26.1866	201.7012	188.9226	325	315	51.703919	55414.34

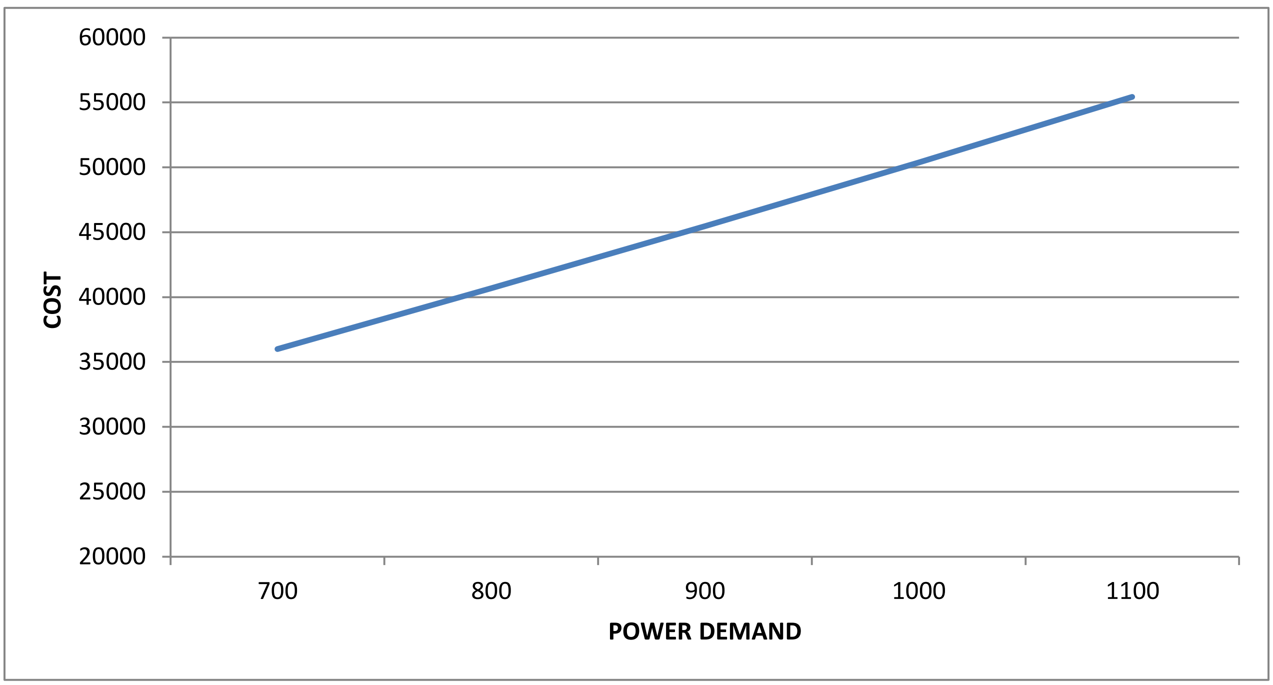


Fig 6 Variation of Cost with Power Demand Curve for Six unit system.

Table 9: lambda iteration method including transmission losses.

SL No.	Power demand	P1	P2	P3	P4	P5	P6	Lambda	Total Fuel Cost	Ploss
1	700	28.3040	10	118.8979	118.6669	230.7332	212.8313	48.997532	36912.15	19.4332
2	800	32.5999	14.4831	141.5440	136.0413	257.6588	243.0034	50.661026	41896.63	25.3307
3	900	36.8636	21.0765	163.9265	153.2239	284.1656	272.7317	52.315997	47045.16	31.9878
4	1000	41.1831	27.7776	186.5561	170.5768	310.8251	302.5631	54.010538	52361.14	39.4818
5	1100	48.1751	36.1684	220.1341	202.4611	325.0000	315.0000	54.813989	57871.60	46.9386

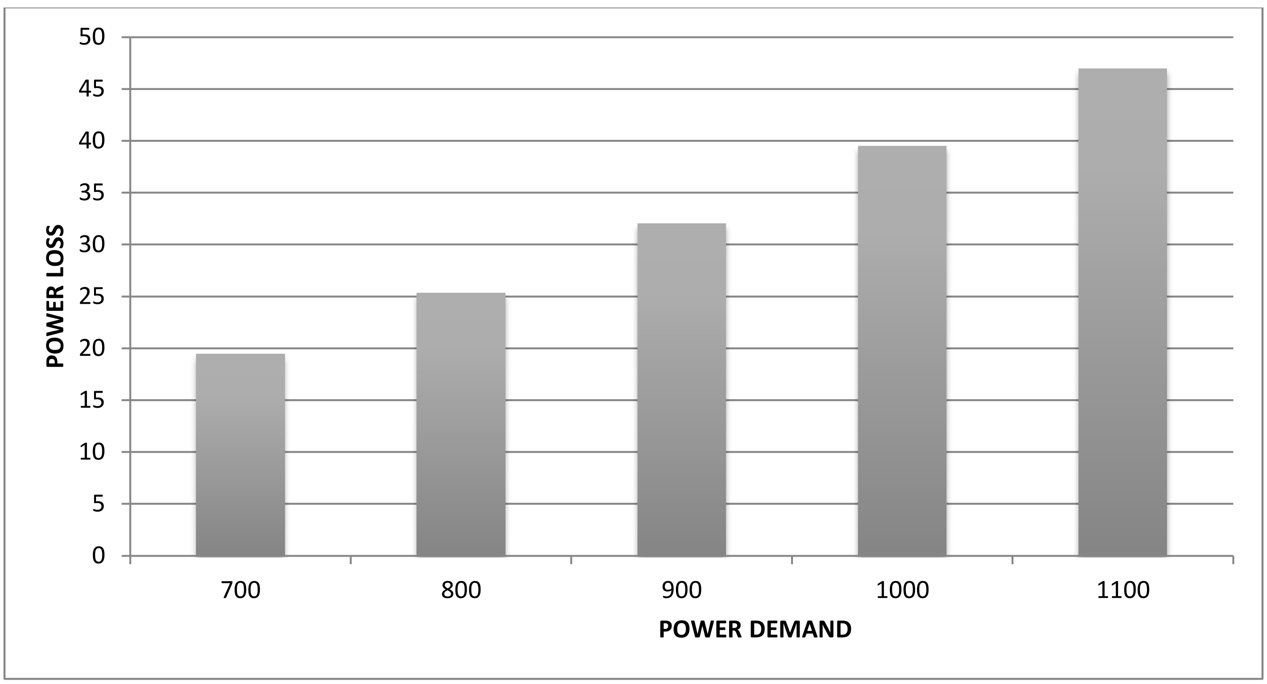


Fig 7: Variation of Power loss with the Load Demand for Six unit system.

PARTICLE SWARM OPTIMIZATION METHOD:

Table 10: Optimal Scheduling of Generators of a Six-unit system by PSO Method (Loss neglected case).

Sl No.	POWER DEMAND (MW)	P1(MW)	P2(MW)	P3(MW)	P4(MW)	P5(MW)	P6(MW)	TOTAL FUEL COST (Rs/hr)
1	800	28.74013	10.00002133	123.2588	126.933	260.04	251.028	40675.9682
2	900	32.51634594	10.79475825	143.6746427	142.9868715	287.1309084	282.8964732	45464.08097
3	1000	36.11488234	15.98564928	163.1347857	158.4553349	312.9788852	313.3304625	50363.69128

Table 11: Comparison of results between Conventional method and PSO method for Six-unit system (Loss Neglected Case).

SI.No.	Power Demand (MW)	Conventional Method (Rs/Hr)	PSO Method (Rs/Hr)
1	800	40675.97	40675.9682
2	900	45464.08	45464.08097
3	1000	50363.69	50363.69128

Table 12: Optimal Scheduling of Generators of a Six-unit system by PSO Method (Loss included case).

Sl No	Power Demand (MW)	P1 (MW)	P2 (MW)	P3 (MW)	P4 (MW)	P5 (MW)	P6 (MW)	TOTAL FUEL COST(Rs/hr)	Loss, PL (MW)
1	800	32.59768442	14.48845674	141.5664943	136.0037228	257.6848641	242.9892988	41896.62871	25.33052121
2	900	36.86889028	21.08289623	163.9647439	153.2207934	284.1119384	272.7371403	47045.15634	31.98640267
3	1100	48.04821465	38.25727999	222.1471275	198.3931315	325	315	57870.36512	46.84575365

Table 13: Comparison of results between Classical Method and PSO method of a Six- unit system (Loss included Case).

Sl No.	Power Demand (MW)	Conventional Method (Rs/Hr)	PSO Method (Rs/Hr)
1	800	41896.63	41896.62871
2	900	47045.16	47045.15634
3	1100	57871.60	57870.36512

Table 14: Reliability Evaluation of PSO method.

Sl No.	Power Demand (MW)	Min(MW)	Mean(MW)	Std Deviation(MW)
1	800	41896.62871	41896.62935	0.001005049
2	900	47045.1563	47045.15674	0.000318944
3	1100	57870.36512	57870.36523	0.000106356

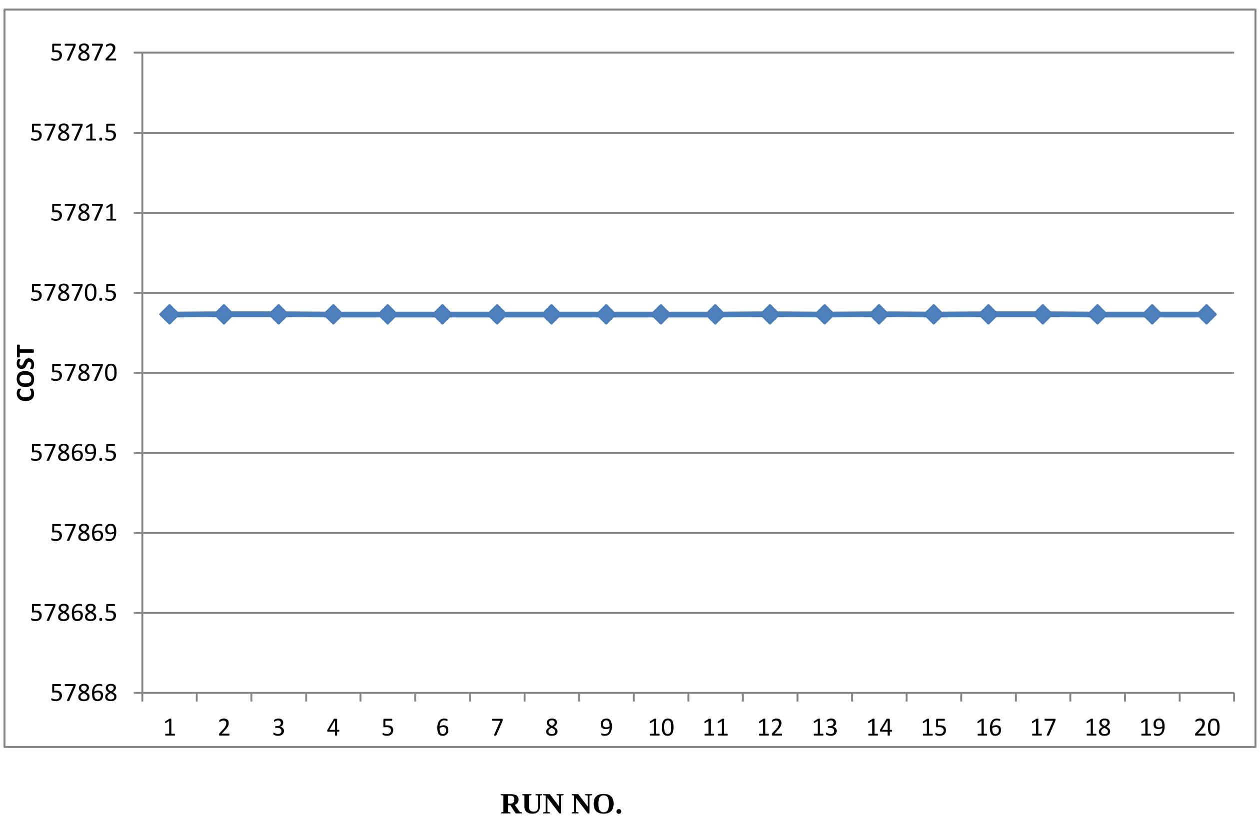


Fig.8: Reliability Evaluation of PSO Method Six unit System.

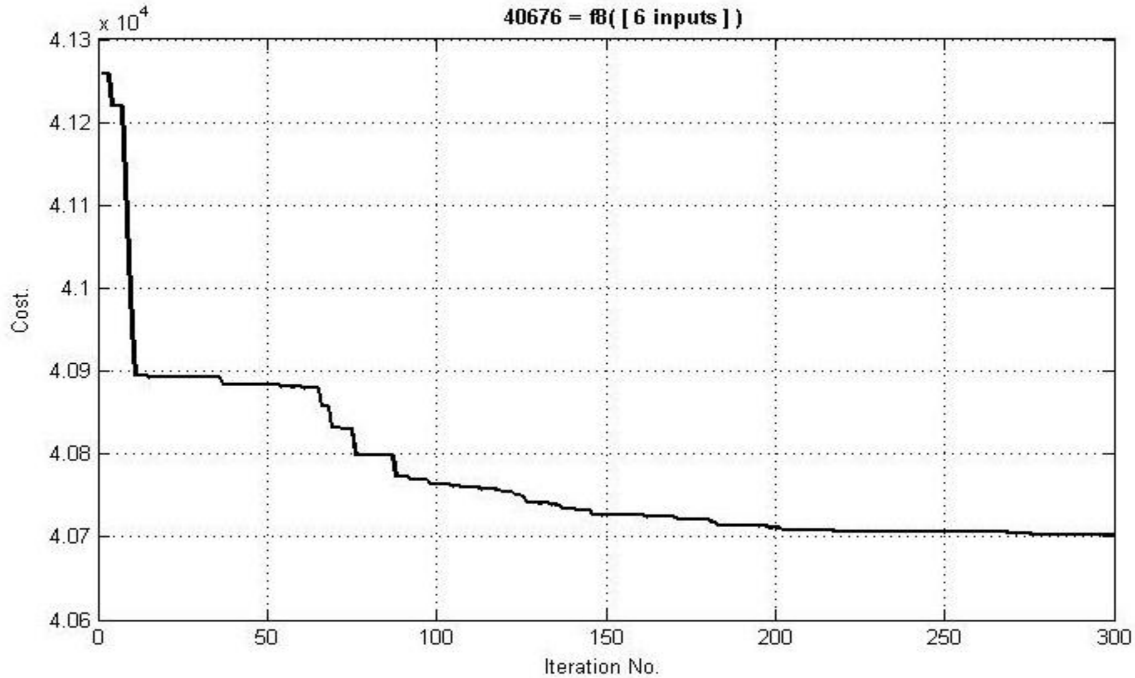


Fig.9 Convergence Characteristics of PSO Method for Six unit System.

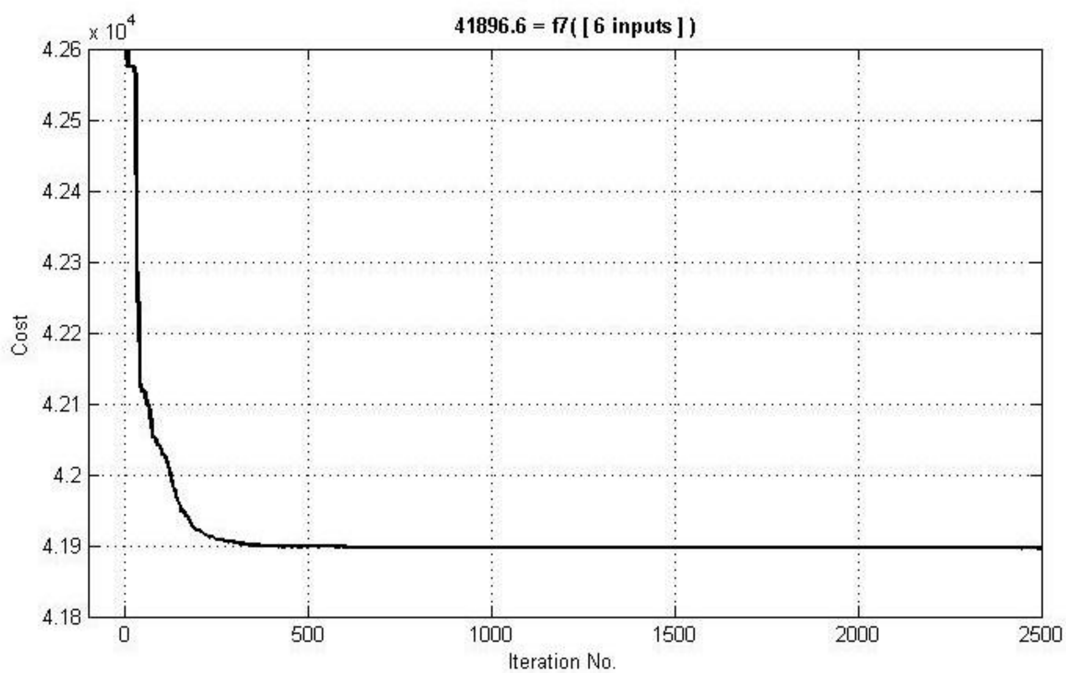


Fig.10 Convergence Characteristics of PSO Method for Six unit System with $ITER_{MAX}$ =100.

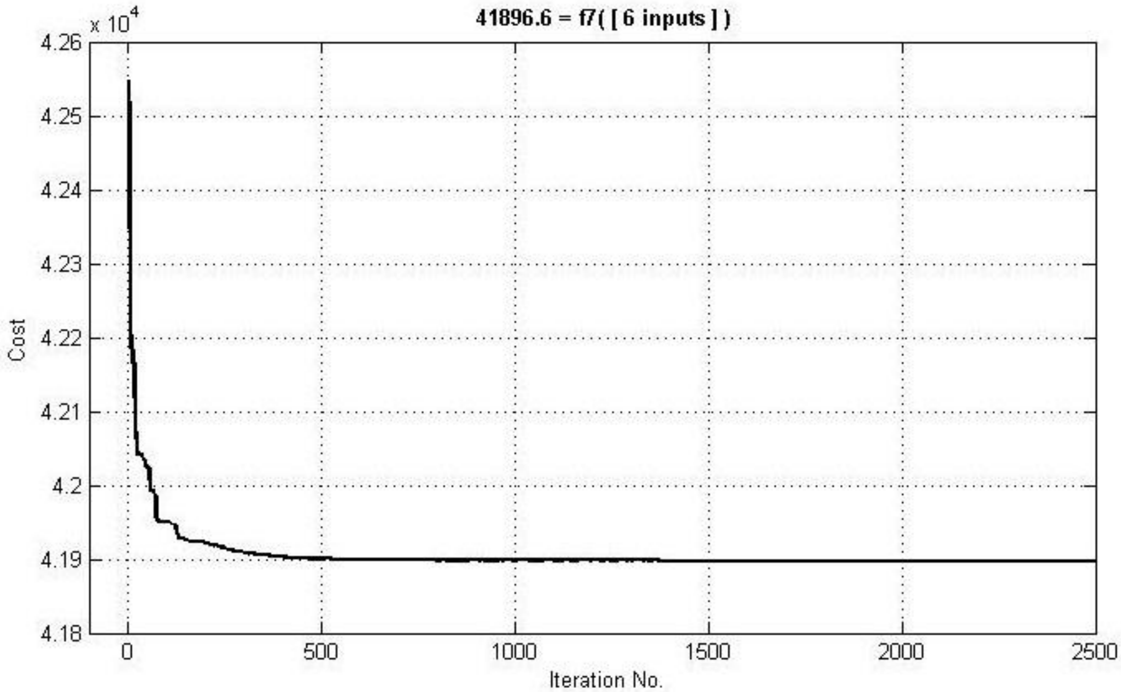


Fig.11 Convergence Characteristics of PSO Method with $ITER_{MAX}$ =1000.

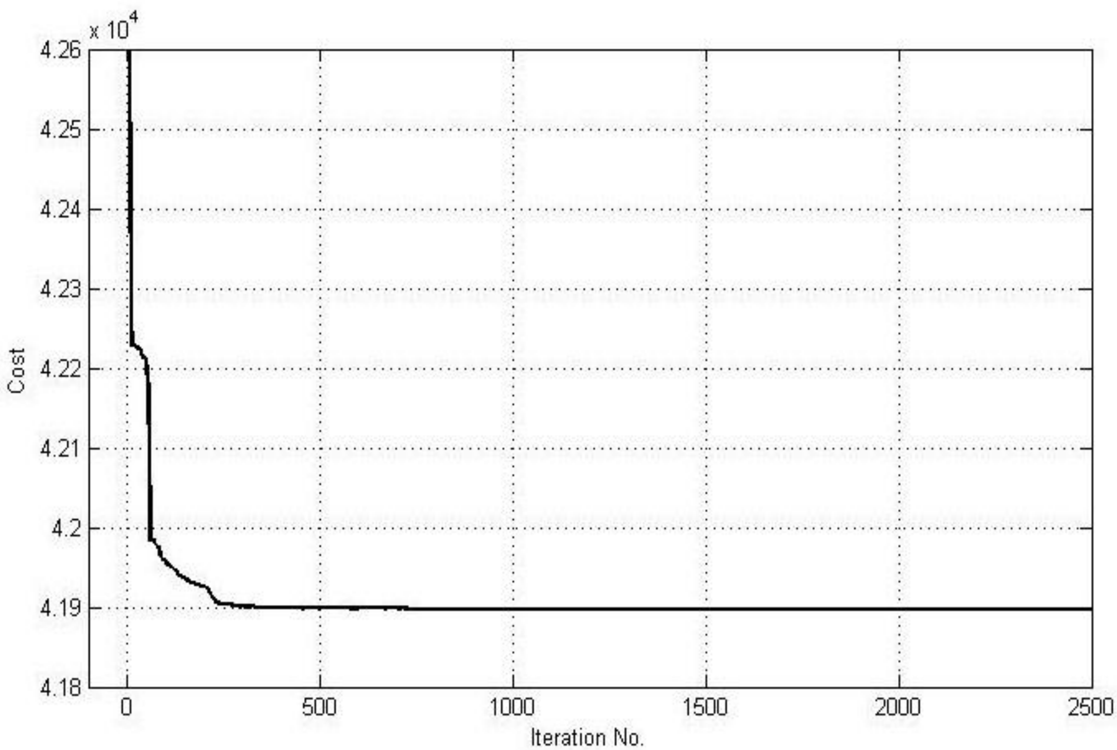


Fig.12 Convergence Characteristics of PSO Method with $ITER_{MAX}$ =2000.

CHAPTER 5:

CONCLUSION

&

FUTURE SCOPE

PSO method was employed to solve the ELD problem for two cases one three unit system and another six unit system. The PSO algorithm showed superior features including high quality solution, stable convergence characteristics. The solution was close to that of the conventional method but tends to give better solution in case of higher order systems. The comparison of results for the test cases of three unit and six unit system clearly shows that the proposed method is indeed capable of obtaining higher quality solution efficiently for higher degree ELD problems. The convergence characteristic of the proposed algorithm for the three unit system and six unit system is plotted. The convergence tends to be improving as the system complexity increases. Thus solution for higher order systems can be obtained in much less time duration than the conventional method. The reliability of the proposed algorithm for different runs of the program is pretty good, which shows that irrespective of the run of the program it is capable of obtaining same result for the problem. Many non-linear characteristics of the generators can be handled efficiently by the method. The PSO technique employed uses a inertia weight factor for faster convergence. The inertia weight is taken as a dynamically decreasing value from Wmax to Wmin at and beyond ITER max. The convergence characteristic of the method for varying ITERmax was analyzed. Values of ITERmax between 1000-2000 give better convergence characteristic, so the value of 1500 is used for optimum results.

Advantages of PSO:

1. It only requires a fitness function to measure the ‘quality’ of a solution instead of complex mathematical operation like gradient or matrix inversion. This reduces the computational

complexity and relieves some of the restrictions that are usually imposed on the objective function like differentiability, continuity, or convexity.

2. It is less sensitive to a good initial solution since it is a population-based method.

3. It can be easily incorporated with other optimization tools to form hybrid ones.

4. It has the ability to escape local minima since it follows probabilistic transition rules

5. It can be easily programmed and modified with basic mathematical and logical operations

6. It is in-expensive in terms of computation time and memory.

7. It requires less parameter tuning.

.

FUTURE SCOPE:

1. PSO algorithm can be combined with other simple optimization techniques to improve their performance when applied to ELD problems and obtain better results.
2. Bus Data and Line Data of the system can be taken as input along with the load demand to obtain the minimization function with constraints on voltage and reactive power at various points of the system.

REFERENCES

[1] Saadat, H. (2010). *Power system Analysis.* Tata Mcgraw hill.

[2] Swarup K.S. , Rohit Kumar P., "*A new evolutionary computation technique for economic dispatch with security constraints*" ;Electrical Power and Energy Systems 28 (2006) pp 273–283

[3] Wadhwa, C.L (2009). *Electrical Power System.* New Age publishers.

[4] Zhu Jizhong (IEEE) 2008, *OPTIMIZATION OF POWER SYSTEM OPERATION*.

[5] Sudhakaran M., D - Vimal Raj P. Ajay and Palanivelu T.G, "*Application of Particle Swarm Optimization for Economic Load Dispatch Problems*" The 14th International Conference on Intelligent System Applications to Power Systems, ISAP 2007.

[6] Lee K.Y. and Park J., *Application of particle swarm optimization to economic dispatch problem:Advantages and disadvantages*, in Proc IEEE PES Power Syst. Conf. Expo. Oct 2006, pp 188-192

[7] Birge, B.," *PSOt, A Particle Swarm Optimization Toolbox for Matlab*", IEEE Swarm Intelligence Symposium Proceedings, April 24-26,2003.

[8] Gaing Zwe-Lee, "*Particle Swarm Optimization to solving the Economic Dispatch Considering the Generator Constraints*", IEEE Trans. On Power Systems, Vol.18, No.3, pp. 1187-1195, August 2003.

[9] D. N. Jeyakumar, T. Jayabarathi, and T. Raghunathan, "*Particle swarm optimization for various types of economic dispatch problems,*" Int. J. Elect. Power Energy Syst., vol. 28, no. 1, pp. 36–42, 2006.

[10] Park, J.-B., Lee K.-S, Shin J.-R, and Lee K. Y, "*A Particle Swarm Optimization for Economic Dispatch with Non-Smooth Cost Functions*," IEEE Transactions on Power Systems, Vol. 20, No. 1, pp. 34-42, February 2005.

[11] R. C. Eberhart and Y. Shi, "*Comparing inertia weights and constriction factors in particle swarm optimization*," in Proc. Congr.Evolutionary Computation, 2000, vol. 1, pp. 84–88.

[12] A. Jiang and S. Ertem, "*Economic dispatch with non-monotonically increasing incremental cost units and transmission system losses*",IEEE Transactions on Power Systems, vol. 10, no. 2, pp. 891-897, May 1995.